



Characterization of oil solvent extracted from four Mango (*Mangifera indica* L.) kernels

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Received: 3 February 2025 / Revised: 30 May 2025 / Accepted: 15 July 2025 / Published online: 25 July 2025
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Abstract

The present study investigates the extraction and potential uses of mango kernel oil using a Soxhlet extractor with *n*-hexane as a solvent from four different varieties of mango (Bush, Dusha, Kent, and Peter). The oil yield, phytochemical screening and quantifications, and fatty acid profiling of extracted oils were determined. The highest oil yields obtained from Bush (17.10%) and Kent (17.80%) indicated the extent of high oil content in the mango varieties tested in this study. The oils comprise different bioactive compounds, and Dusha has shown significant phytochemical and physicochemical characteristics. Kent has the highest iodine value out of all samples, making it unsaturated and prone to easier oxidation. Since the oils have different fatty acid profiles, Dusha would be better for heart-healthy diets and cooking, while Kent would be better for nutritional purposes. Most of the tested attributes differed significantly ($p < 0.05$) across the selected varieties. Based on the results of this study, the mango kernel oils from the examined varieties are promising sources of valuable components for the production of nutraceuticals due to their potent antioxidant properties and favourable profile of oleic fatty acids. The study also emphasises the importance of selecting the right mango variety and optimising extraction techniques for sustainable utilisation of mango seed waste.

Keywords Solvent extraction · Oil characterization · Mango kernel · Phytochemicals · Fatty acids

Introduction

In most fields of technology and pharmacy, there is greater demand for natural compounds over synthetic ones. Such interests plummeted into importance and commerce for improving food and health functional products that can be employed for various diseases [1]. Mango and its by-products have recently been the subject of increasing interest, mainly because of their nutritional value as edible tropical fruits distributed all over the equatorial countries. Mango, *Mangifera indica* L., belongs to the family Anacardiaceae, one of the main tropical fruit plants. Native to South and

Southeast Asia, it is sometimes extensively naturalised and is now present worldwide, including wider African nations [2]. The mango kernel is an underutilised by-product of the mango fruit that is often wasted. Mango kernels are rich in high levels of essential fatty acids like stearic, oleic, palmitic, and linoleic acids [3]. These can be highly nutritious, scarifier in mineral and antioxidant contents, a moderate source of protein, as well as vitamins such as C, B1, and B2 [4]. Mango kernels also have the potential to serve as a source of dietary fibre. They can also be used in the production of dietary supplements and functional food ingredients in a wide range of formulations [5, 6].

Although mango fruits are popular and economically valuable, the seeds from their fruits are not utilised but discarded as kitchen waste. Therefore, using this residual raw material to produce oils can boost its worldwide sustainability [5, 7]. Jethro et al. [8] observed that using the seed kernels to extract their oils is advantageous, whereas mango seems to have an abundance of seed kernels. Oil extraction from mango kernels is a nice solution to reduce environmental impacts. Moreover, it is also one of the approaches to a circular economy, waste minimisation, and

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sustainable resource management [3]. Mango kernel oil is used in cosmetics for skin smoothness and freshness and as a raw material in industrial oils like lubricants, surfactants, and biodiesel for maintaining skin appearance [9]. Mango kernel oil contains a substantial amount of fatty acids such as oleic acid, linoleic acid, and arachidic acid, as well as antioxidant compounds like tocopherols and tocotrienols, which contribute to its potential applications in both food and skin treatment products [3, 4]. Some research on mango kernels was also performed, including using seed kernel oil to produce polyol esters [8].

Therefore, examining the production of mango kernels oil, there is a need for physicochemical properties such as pH, viscosity, specific gravity and density, titratable acidity, acid value, iodine value, peroxide value, and saponification value of the mango kernels oil to be thoroughly checked. This will help ensure the oil's quality and effectiveness in various applications. Earlier, the extraction methods of mango kernels oil were either conventional techniques using different organic solvent extraction methods or advanced extraction approaches such as accelerated solvent extraction, cold press, hot press, ultrasonic-assisted extraction, and enzyme-assisted extraction [6, 10–13]. However, solvent extraction from biomass is one method of obtaining valuable compounds for industrial applications. It is estimated that a large sector of the chemical process industry is concerned with extracting natural products using organic solvents to produce flavours, fragrances, spices, vegetable oils, marine oils, and animal oils as food ingredients [14, 15].

This research aimed to extract oil from mango kernels using *n*-hexane solvent, characterise the physicochemical properties, and assess the oil's stability. There are few newsworthy published data on mango kernel oil, especially after oil extraction from the kernels using *n*-hexane as a solvent. These results could provide valuable insights into the potential applications of mango kernel oil in various industries, such as cosmetics and pharmaceuticals. Therefore, this study assessed the potential of oil produced from the kernels of Bush, Dusha (Hindi), Kent, and Peter mango cultivars. The selection of these cultivars was predicated on their distinctive attributes, geographical and economic significance, and potential oil yield. The physicochemical characteristics of mango kernel oil are crucial for assessing its quality, stability, and applicability in food, cosmetics, and industrial uses. These characteristics assist in evaluating its consumability, longevity, processing requirements, and possible uses. The possible positive effect of this research lies in its contribution to information on the potential use of mango kernel oil as a nutritional additive with the increasing production of mango fruit and a wide range of by-products.

Materials and methods

Research materials and sample preparations

The mango varieties Bush, Dusha (Hindi), Kent, and Peter utilised in this study were procured from the fruits and vegetable market at Yola by-pass, Jimeta, Yola, Adamawa State, Nigeria. This study focuses on Bush, Dusha (Hindi), Kent, and Peter mango cultivars due to their unique agro-nomic and taste requirements, widespread cultivation, and plant-based compounds. Kent yields high-unsaturated oil, suitable for industrial use. Dusha and Bush are local varieties that have limited scientific attention but are widely consumed. Peter, a local cultivar, is another regional cultivar to understand kernel oil content and composition [16]. This study offers a broader view of mango kernel oil for food, cosmetic, and industrial needs due to the different mangoes used. The taxonomist at the Department of Crop Production authenticated these mango varieties. Five (5 kg) of each mango variety were weighed, cleaned with tap water, and then peeled with a kitchen knife to extract the seed. The seeds were desiccated in sunlight at an average temperature of 40 to 45 °C for three days. The desiccated seeds were fractured to extract the kernels; then, they were milled using a Kenwood blender will Mill (BLP15.150WH, China) into a fine powder.

Chemicals and reagents

Necessary chemicals and reagents for mango kernel oil analysis are *n*-hexane, methanol, sulphuric acid (H_2SO_4), hydrochloric acid (HCl), potassium hydroxide (KOH), sodium hydroxide (NaOH), phenolphthalein indicator, Wijs reagent, sodium thiosulphate solution ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$), starch indicator, potassium iodide (KI), Acetic acid, perchloric acid and chloroform, distilled water, fatty acid methyl ester (FAME) standard mixture, anhydrous sodium sulphate (Na_2SO_4), and distilled water. All these chemicals and reagents were of analytical standard. They were purchased from Sigma-Aldrich, a subsidiary of Merck KGaA, Darmstadt, Germany.

Technique for oil extraction

The solvent extraction technique outlined by Hussein et al. [17] and Ilesanmi et al. [18] was utilised with minor modifications. One thousand five hundred grammes (1500 g) of mango kernel powder was encased in muslin fabric and positioned into a 1500 mL conical flask. The flask contained 500 mL of *n*-hexane solvent and was securely sealed at its opening. The sample was permitted to remain for 12 h for oil to be extracted. The experimental apparatus was

subsequently heated using a controlled water bath at 70 °C. The solvent and oil were separated, and the solvent was retrieved using distillation. These procedures were repeated for the other varieties, and the oil extracted was taken for the phytochemical screening. Figure 1 shows a flow chart for the extraction processes, while Fig. 2 shows the pictures of the extracted oils.

Determination of the percentage oil yield

The percentage oil yield was calculated as outlined by Hussein et al. [17] and Ilesanmi et al. [18].

$$\text{Percentage Oil Yield (wt. \%)} = \frac{\text{Volume of the Oil (g)}}{\text{Weight of Sample (g)}} \times 100. \quad (1)$$

Phytochemical screening in the extracted oils

The extracted oils were analysed for the presence of the following phytochemicals: tannins, saponins, steroids, terpenoids, flavonoids, glycosides, anthocyanins, triterpenoids, coumarins, emodins, and alkaloids.

Test for tannins

To detect the presence of tannins, 2 mL of 5% ferric chloride was added to 1 mL of oil extract. A greenish-black colouration indicated the presence of tannins [19].

Test for saponins

A portion (approximately 1.5 g) of extracted oil was vortexed in a test tube with water. Regular foaming showed the early presence of saponins [20].

Test for steroids

The extracted oil (2 mL) was treated with chloroform and filtered. The filtrate was added with a few drops of concentrated H_2SO_4 , shaken, and allowed to stand. The formation of a red colour at the lower layer suggests the presence of steroids [20].

Test for terpenoids

The extracted oil sample (5 mL) was mixed with chloroform (2 mL). After that, 3 mL of concentrated H_2SO_4 was added slowly to form a separate layer. The reddish-brown colour of the inner phase represents terpenoids [21].

Test for flavonoids

Flavonoids were detected by adding 2 to 3 drops of concentrated H_2SO_4 to 1 mL of the natural oil extract. The observation of orange to crimson red colour describes the presence of flavonoids Hussein et al. [17].

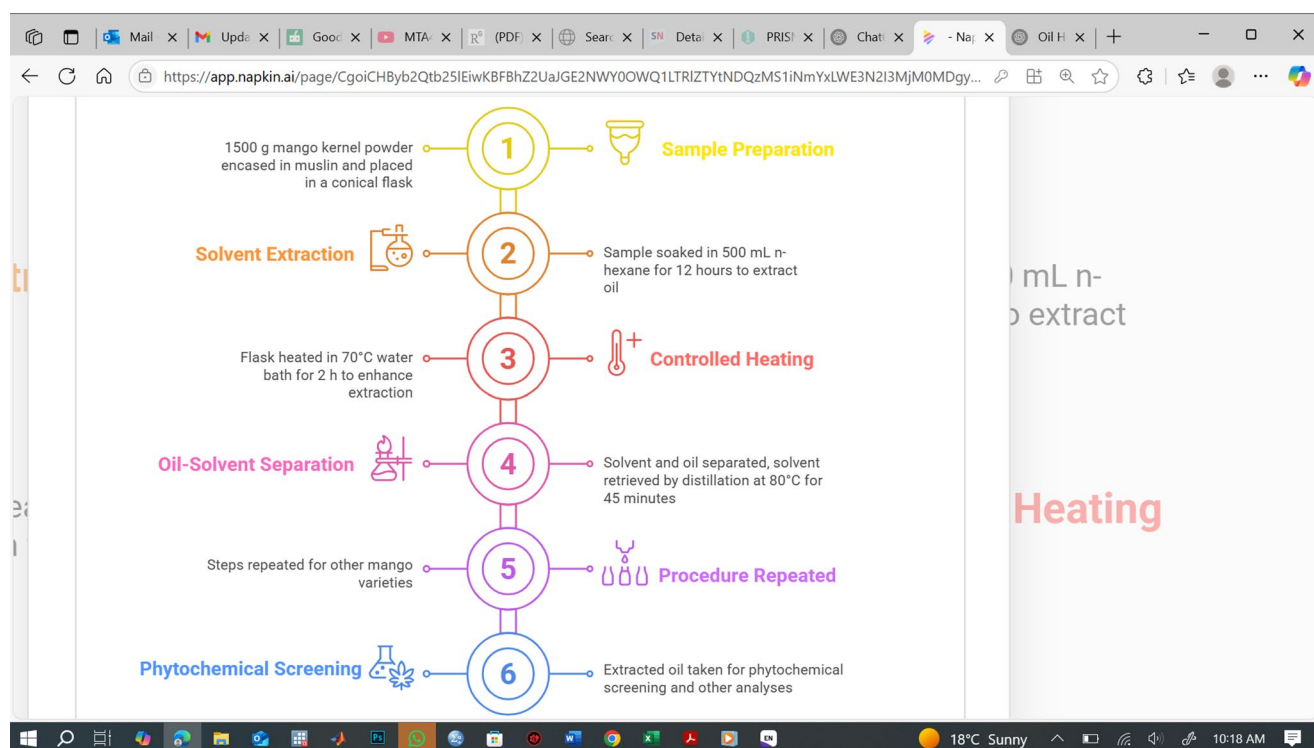


Fig. 1 Flow chart for the extraction oil

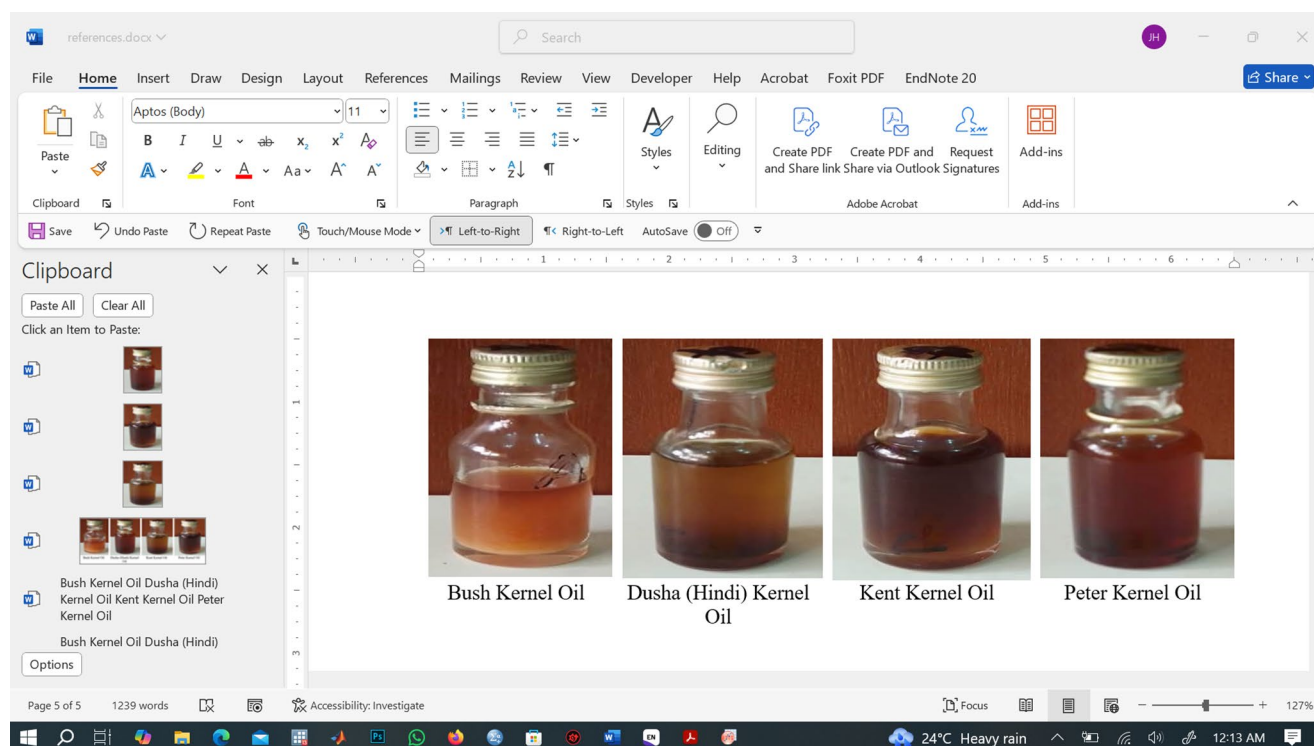


Fig. 2 Extracted oil samples

Test for glycosides

Two drops of a 5% FeCl_3 solution and 2 mL of glacial acetic acid were mixed with five (5 mL) extracted oil. A brown ring formation between the layers showed the glycoside's presence [22].

Test for anthocyanin

To detect the presence of anthocyanin, 1 mL of 2 N NaOH was added to 2 mL of oil extract and then heated for 5 min at 100°C . A yellow colouration shows the presence of anthocyanin [19].

Test for triterpenoids

Ten (10 g) of the extracted oil sample were dissolved in 1 mL of chloroform, and 1 mL of acetic anhydride was added after 2 mL of concentrated H_2SO_4 . The yellow colour nearest to the bottom of the solution shows the presence of triterpenoids [20].

Test for coumarins

To 2 mL of the aqueous extract of the extracted oil sample, three (3 mL) of a 10% NaOH solution were added. The

formation of yellow colouration in the solution suggests the presence of coumarins [17].

Test for Emodins

Five (5 mL) of the oil sample extracted was mixed with 2 mL of NH_4OH and 3 mL of benzene. The presence of emodins is confirmed by the observation of a red colouration [23].

Test for alkaloids

A few drops (1–2) of Dragendorff's reagent (potassium bismuth iodide solution) were added to 1 mL of the oil extract in a test tube. The presence of alkaloids results in a reddish-brown precipitate [20].

Quantitative determination of phytochemicals

The procedure AOAC [24] was used with slight modifications to determine the concentration of phytochemicals in the extracted oils. The oil sample (3.5 g) was dissolved in 1.0 mL *n*-hexane and placed in a vial. The resulting sample was injected into a Buck Scientific (USA) BLC10/11 High-Performance Liquid Chromatograph (HPLC). The HPLC system was fitted with a fluorescence detector (excitation 295 nm and emission 325 nm) and an analytical silica

column (25 cm × 4.6 mm ID, 5 µm, stainless steel). The mobile phase used was hexane: tetrahydrofuran: isopropanol (1000:60:4 v/v/v) at a 1.0 mL/min flow rate. A similar procedure was also used to prepare the standard samples. Phytochemical concentrations were quantified by comparing sample chromatograms to those of reference standards. The concentration of phytochemicals in the sample was determined using the formula below.

$$\text{Phytochemical Concentrations (ppm)} = \frac{A_S \times \text{STD (ppm)} \times V_{\text{HEX}} (\text{ml})}{A_{\text{STD}} \times \text{Weight of sample (g)}}. \quad (2)$$

Where;

A_S = Area of the sample STD = Concentration of the standard.

V_{HEX} = Volume of hexane A_{STD} = Area of the standard.

Determination of physicochemical properties of the extracted Mango kernel oils

Determination of iodine value

The iodine value was determined using AOAC [25] Method No. Cd 1–25. Oil extracted from mango kernel was digested in the volumetric flask (with lid) using 5 mL of carbon tetrachloride (CCl_4) and 25 mL of Wijs solution. The flask was then distilled for an hour in the dark with 20 mL of a 15% potassium iodide solution and 25 mL of distilled water. The flask solution was then titrated against $\text{Na}_2\text{S}_2\text{O}_3$ and a freshly prepared starch indicator was added. The reading was observed without executing the sample. The iodine value of the extracted oil was calculated as specified by Eq. 3.

$$\text{Iodine Value (g/100g)} = \frac{(B - S) \times 12.69 \times N}{\text{weight of sample (g)}}. \quad (3)$$

Where; N is the normality of $\text{Na}_2\text{S}_2\text{O}_3$, S is the volume of $\text{Na}_2\text{S}_2\text{O}_3$ used in the sample, and B is the volume of $\text{Na}_2\text{S}_2\text{O}_3$ used in the empty sample.

Determination of peroxide value

The peroxide value of the extracted oil was determined using the AOAC [25] Method No. Cd 8b-90 procedures. The 5 g was mixed with 250 mL in an Erlenmeyer flask. These were then added with 30 mL of glacial acetic acid, a mixture in chloroform solution. Once covered, the flask was gently agitated for about a minute to dissolve the oil thoroughly in the solvent mixture. Then, add 0.5 mL of freshly prepared potassium iodide (KI) solution to the beaker. A constant

stream of stirring was applied to the solution while titrating it against a 0.1 N standard sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$) solution until the yellowish hue disappeared completely. Then, 0.5 mL starch solution was used as an indicator, and the titration was carried out with vigorous stirring until the dark blue colour disappeared. Individual measurements of empty readings were conducted without sample runs. The concentration of peroxide is determined using the formula in Eq. 4.

$$\text{Peroxide Value} = \frac{(B - S) \times N \times 1000}{\text{weight of sample (g)}} \times 100. \quad (4)$$

Where; N is the normality of $\text{Na}_2\text{S}_2\text{O}_3$, S is the volume of $\text{Na}_2\text{S}_2\text{O}_3$ used in the sample, and B is the volume of $\text{Na}_2\text{S}_2\text{O}_3$ used in the empty sample.

Determination of saponification value

The saponification value of the mango kernel oil was determined as described by AOAC [25], Method No. CD 3a-94. The sample weighing 2 g was taken in a conical flask and dissolved in 25 mL of 0.5 N alcoholic potassium hydroxide solution. After that, the reaction mixture was refluxed for 30 min through the water condenser in the water bath. The solution generated was then cooled to room temperature and titrated with a 0.5 N HCl solution, adding 1 mL of phenolphthalein indicator. The empty reading was measured independently.

$$\text{Saponification value} = \frac{(B - S) \times 0.02805 \times 1000}{\text{weight of sample (g)}}. \quad (5)$$

Determination of acid value

The acid value of mango kernel oil was determined as described by AOAC [25]. In a conical flask, one gramme (1 g) of oil sample was diluted, preferably in 50 mL of ethanol, and 2 to 3 drops of phenolphthalein indicator were added and titrated with 0.1 N potassium hydroxide solution (KOH) to a pink endpoint. The acid value was determined using Eq. 6.

$$\text{Acid value} = \frac{V \times C \times 56.1}{\text{weight of sample (g)}}. \quad (6)$$

Where; V represent the volume of KOH solution consumed during titration, measured in mL; C denote the concentration of the KOH solution, expressed in mol/L; and 56.1 signify the molar mass of potassium hydroxide, in g/mol.

Determination of titratable acidity of the oil

In the study, the sample oil's titratable acidity (TA) was analysed according to the methodology described in AOAC [25]. A total of 10 mL of oil extract was transferred to a beaker and titrated with 0.1 N sodium hydroxide (NaOH) solution, using phenolphthalein solution as an indicator. Titratable acidity was determined as a percentage of oleic acid.

$$\text{Titratable acidity (TA)} = \frac{V \times N \times \text{Titre value}}{\text{Volume of Sample Used}} \times 100. \quad (7)$$

Where; V represents the volume of NaOH in litres (L) and N denotes the normality of NaOH.

Determination of specific gravity and density of the oil

The specific gravity of mango kernel oil was determined according to the procedure outlined by AOAC [25]. The specific gravity bottle was cleansed with detergent, rinsed with distilled water, dried, and subsequently weighed (w_1). The bottle contained water and had a weight of (w_2). Subsequent to the dried bottle, it was filled with a sample of oil and weighed (w_3).

$$\text{Specific gravity} = \frac{w_3 - w_1}{w_2 - w_1} \times 100. \quad (8)$$

Where:

W1=weight of the empty specific gravity bottle.

W2=weight of the specific gravity bottle containing water.

W3=weight of the bottle containing the oil sample.

The following equation was employed to determine the density of oil.

$$\text{Density of oil} = \text{Specific gravity} \times \rho_{\text{water}}. \quad (9)$$

Where; ρ_{water} represents the density of water, which is 1000 kg/m³.

Determination of pH value

The pH, an indicator of a substance's acidity or alkalinity, was assessed utilising a digital pH meter (Model: EQ-610 Equip-Tronics) following the AOAC [25] protocol. The oil samples were transferred into four beakers, and the pH meter probe was employed to assess their corresponding pH levels.

Determination of viscosity of oil

The oil's viscosity was evaluated following the Brookfield method from the ASTM [26], guidelines D2983. The viscosity was measured using a rotational viscometer (Model: Visco elite-R, V4002). The oil is held in a glass tube for this test and placed in a temperature-controlled insulated block (40°C). The oil is subjected to a metal spindle that is rotated at a constant speed, allowing for torque required to maintain its rotation to be recorded. The absolute viscosity of the oil was calculated based on the rotation resistance under the induced shear stress of the oil. The absolute viscosity is given in centipoise (cP=mPa.s, SI units).

Determination of smoke, flash and fire point

The smoke, flash, and fire points were measured according to the method given by AOCS [27]. The oil sample with 25 mL in a beaker was placed on a heating device (electric heater). A thermometer was suspended vertically in the middle of a beaker, and the bottom of the bulb was about 6.35 mm from the base. The sample was immediately heated to approximately 42°C, and the temperature was ramped at 60 °C/min. We refer to the “smoke point” as the temperature at which smoke first appears, some specific temperature at which oil emits abundant smoke. The oil is heated constantly until the smoke point is exceeded. A small igniting source (a tiny flame) was carefully passed quickly over the surface of the oil at regular intervals. The flash point is the temperature at which volatile substances ignite quickly but do not sustain combustion. The oil still heats at the same steady rate until it crosses the flash point. A flame was applied to the upper rim of the beaker repeatedly, and time was recorded until the oil caught fire. This was the point at which they recorded the temperature on the thermometer, known as the fire point.

Determination of fatty acid profile

Fatty acids in extracted oils were determined by High-Pressure Liquid Chromatography (HPLC) (Buck Scientific BLC 10/11 USA) according to the method described by AOAC [24]. Hexane was used as a solvent to extract the oil content of the samples using a Soxhlet extractor. They were converted to methyl esters via the ISO process (ISO, Method 5509, 2015). Fatty acid methyl esters (FAMES) were isolated using petroleum ether and analysed using an HPLC system with a fixed-wavelength UV detector. The mobile phase comprises 59:41 acetonitrile and 2-propanol, and the column is a Prevail C-18 (5 μ m, 150×4.6 mm) with a 1 mL/min flow rate. The temperature of the oven was maintained at 210°C for 45 min. Peak identification was carried out by comparing the retention times of authentic fatty acid

standards with those extracted from samples using the Peak Simple chromatography data system processor (Buck Sci. Chromatopac data processor). The fatty acid composition was expressed as a % of total fatty acids.

Statistical analysis

All measurements were triplicate, with results reported as means $\pm$ standard error (SE). Statistical analysis was performed with ANOVA to determine the significance of differences between measurements using SPSS statistical software (Version 22.0; SPSS Inc., Chicago, IL, USA). Duncan's Multiple Range Test was applied to evaluate the significance of the means at a confidence limit ($p > 0.05$).

Results and discussion

Percentage yield of Mango kernel oil

Figure 3 shows the percentage of oil yield from 4 varieties of mango kernels using solvent extraction methods. The oil extraction yields from the four mango seed varieties using *n*-hexane as a solvent are 10.7%, 14.4%, 17.1%, and 17.8% for bush kernel oil, Dusha (Hindi) kernel oil, Kent kernel oil, and Peter kernel oil, respectively. These results indicate

substantial differences in the oil content among the various mango varieties. The relatively highest yields in Bush kernel oil (17.1%) and Kent kernel oil (17.8%) imply that these varieties may possess a higher oil content or possibly due to the specific composition of their mesocarp, kernel, or overall fat content. In contrast, Peter kernel oil (10.7%) showed the lowest yield, possibly due to its lower lipid content or structural factors that impede solvent penetration during extraction. Research conducted by Yadav et al. [28] found oil yields from 10 to 30% for different mango varieties and extraction methods, consistent with current findings, particularly the highest yields in Bush kernel oil and Kent kernel oil. Likewise, Mas'ud et al. [29] and Balacuit et al. [30] also showed that mango kernel oil extraction yields varied, with mango varieties and extraction methods resulting in extraction yields of 4.68–9.38%. On the other hand, the lower yield for Peter (10.7%) suggests that this variety has a less efficient oil composition or that the extraction process needs to be refined.

Moreover, the results of the present study are slightly lower than those observed by Awolu and Manohar [31], who recorded a high oil yield of 19.86% using a different mango variety. This discrepancy can be due to differences in mango varieties or the efficiency of the *n*-hexane solvent extraction process. However, oil yields differ greatly depending on variety, geographic location, extraction method, and

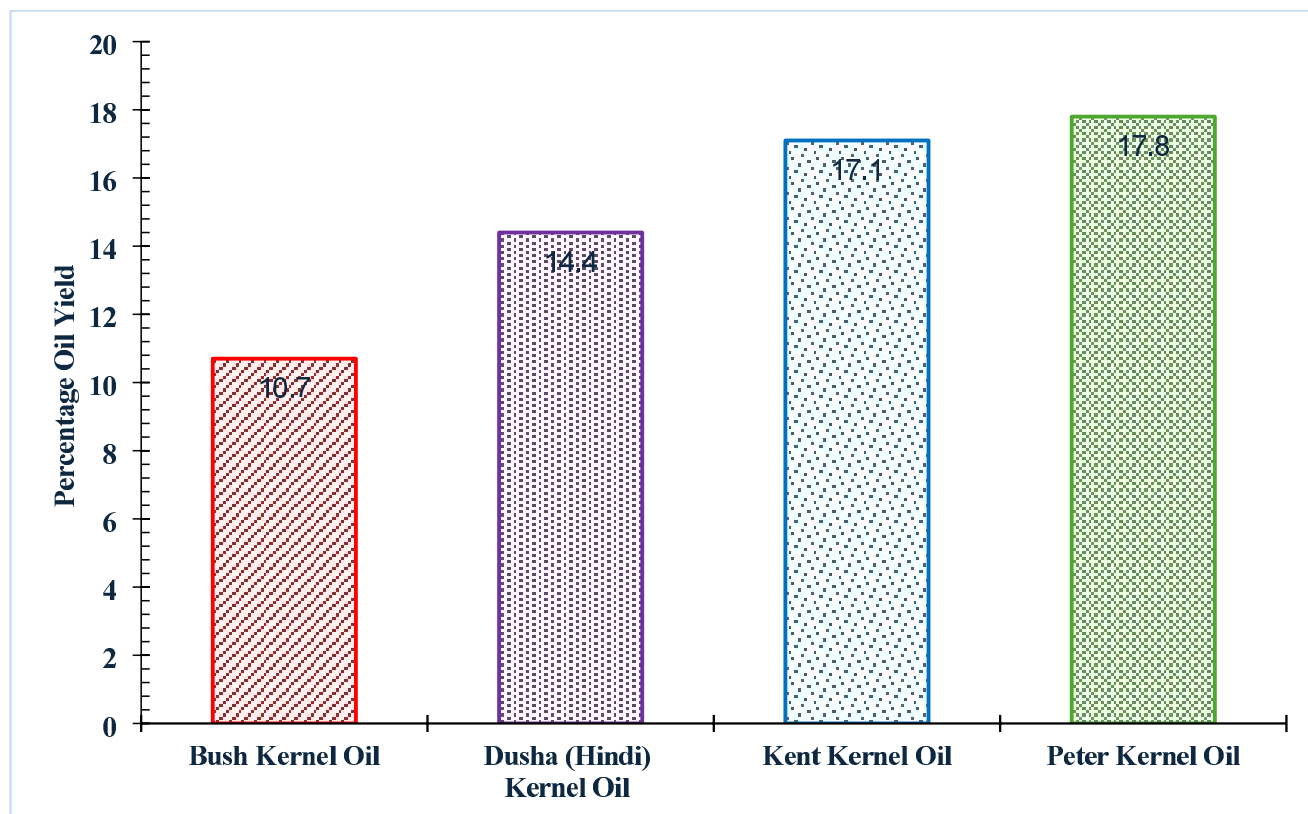


Fig. 3 Percentage oil yield of mango kernel oil

conditions. Hence, these yield discrepancies reinforce the importance of choosing the right variety for oil production depending on the expected yield and application. These results highlight the importance of ensuring that researchers and producers consider these factors when selecting mango varieties best suited for oil extraction.

Phytochemical composition of Mango kernel oils

Qualitative analysis of the extracted mango kernel oils showed the presence of a wide variety of bioactive compounds, including tannins, saponins, steroids, terpenoids, flavonoids, glycosides, anthraquinones, triterpenoids, coumarins, anthocyanins, emodins, and alkaloids, in all the samples. This was followed by quantitative analysis; the results are represented in Table 1, which shows a complete profile of the phytochemicals present in the oils extracted from the four mango seeds (Bush, Dusha (Hindi), Kent, and Peter). These phytochemicals are responsible for the functional properties of the oils and their considerable health benefits, making them potentially useful in nutrition, medicine, and cosmetics. The tannin content ranged from 12.65 to 21.65 g/100 g, with Dusha (Hindi) kernel oil demonstrating the highest tannin aggregation (21.62 g/100 g), while Kent kernel oil exhibited the lowest (12.65 g/100 g). Dusha (Hindi) kernel oil's high level of tannins indicates strong antioxidant properties, making it highly viable for application in the food preservation industry and cosmetic formulations where oxidative stability is critical. Ravindran and Sivakanesan [32] reported that mango kernel oils

with higher tannin content exhibited better antimicrobial and antioxidant activity. This supports our observation that the higher tannin content correlated positively with higher antioxidant potential. Tannins are polyphenolic compounds known for their antioxidant, protein-binding, astringent, antimicrobial properties, and so on. Tannins also prevent microbial growth, which helps extend food products' shelf life [5]. Thus, the higher tannin content of Dusha (Hindi) kernel oil suggests it can play a significant role in food preservation.

The saponin content of the mango kernel oil varied from 18.32 to 27.47 g/100 g, where Kent kernel oil has the highest saponin content (27.47 g/100 g), and Peter kernel oil has the lowest saponin content (18.32 g/100 g). The increased saponins found in Kent kernel oil may have health benefits, at least for lowering cholesterol, improving cardiovascular health, and other potential related outcomes. Fitmawati et al. [33] indicated a positive correlation between saponin content and cardioprotective and anti-inflammatory activities, suggesting the health benefits of Kent kernel oil. Saponins are glycosidic compounds characterised by their surfactant (foaming) properties and are known for a range of biological activities, including immune system modulation and cholesterol-lowering effects [34]. They also have antimicrobial and anti-inflammatory effects. Zahoor et al. [16] reported that saponins in mango kernel oils affect their potential health benefits, so Kent kernel oil is a new possibility for developing heart health-related products.

The steroid content in all mango kernel oil samples ranged from 0.44 g/100 g (Kent) to 6.93 g/100 g, with Dusha (Hindi) kernel oil displaying the maximum steroid content (6.93 g/100 g), which may reflect strong anti-inflammatory properties. In contrast, Kent kernel had the minimum steroid content (0.44 g/100 g). Kent kernel has higher steroid content, which indicates its therapeutic capacity. Studies by Kim et al. [35] and Nguyen et al. [36] highlight that steroid contents in mango kernel oils are necessary for inhibition against inflammation. As such, the Kent variety could serve the best for medicinal use. When we read about steroids in oils, they are most commonly recognised as anti-inflammatory drugs or as immune system endorsers. They are understood as molecules for synthesising hormones in the organism [37].

The terpenoid content of mango kernel oil was between 1.36 and 6.13 g/100 g, with the highest amount in Kent kernel oil (6.13 g/100 g), which could lead to increased antioxidant and antimicrobial activities. On the other hand, Dusha (Hindi) kernel oil had the lowest contents (1.36 g/100 g). According to Mwaurah et al. [3], mango kernel oils are effective against pathogenic microbes, including those with high terpenoid contents and high antimicrobial properties. That suggests that Kent kernel oil could be especially helpful in

Table 1 The HPLC results of the phytochemical properties of Mango kernel oils from the selected varieties of Mango seeds (g/ 100 g)

Phyto-chemicals	Bush Mango Kernel	Dusha Mango Kernel	Kent Mango Kernel	Peter Mango Kernel
Tannins	19.14±0.02 ^b	21.62±0.01 ^a	12.65±0.01 ^d	16.44±0.02 ^c
Saponins	21.67±0.02 ^c	23.42±0.01 ^b	27.47±0.02 ^a	18.32±0.01 ^d
Steroids	3.28±0.04 ^b	6.93±0.01 ^a	0.44±0.01 ^d	1.18±0.01 ^c
Terpenoids	2.88±0.02 ^c	1.36±0.01 ^b	6.13±0.01 ^a	3.87±0.02 ^b
Flavonoids	31.34±0.01 ^a	16.87±0.01 ^d	22.40±0.01 ^c	28.92±0.01 ^b
Glycosides	8.35±0.00 ^a	5.65±0.01 ^b	4.16±0.02 ^d	5.46±0.01 ^c
Anthraquinones	1.16±0.02 ^d	1.83±0.01 ^c	2.42±0.01 ^b	3.15±0.01 ^a
Triterpenoids	0.24±0.02 ^d	0.26±0.01 ^c	1.82±0.01 ^a	1.06±0.01 ^b
Coumarins	0.17±0.02 ^d	0.53±0.01 ^b	1.55±0.01 ^a	0.25±0.01 ^c
Emodins	0.71±0.02 ^c	0.87±0.01 ^b	1.29±0.06 ^a	0.85±0.01 ^b
Alkaloids	5.34±0.02 ^d	7.32±0.01 ^b	6.44±0.01 ^c	9.24±0.01 ^a

Values are means±SE (*n*=3). Different superscripts within the same row show significant differences in mean values among the selected mango varieties

preserving food or creating natural antiseptics. Terpenoids, a large class of organic compounds derived from terpenes, are appreciated for their aromatic properties and potential antioxidant, anti-inflammatory, and antimicrobial activities.

The content of flavonoids in mango kernel oil ranged from 16.87 to 31.34 g/100 g, among which Bush kernel oil contained the maximum number of flavonoids (31.34 g/100 g), while Dusha (Hindi) contained the least number of flavonoids (16.87 g/100 g). Bush kernel possesses the capability for protecting genes against oxidative stress because of its high flavonoid content. As noted by Fitmawati et al. [33] and Lenucci et al. [38], the use of mango kernel oils with a higher flavonoid content corresponds with the more potent antioxidant and anti-inflammatory effects observed, further indicating the benefits of Bush kernel oil for potential health-beneficial formulations. Flavonoids are well known for their potent antioxidant properties, which help lower the risk of chronic diseases like heart disease and cancer [39]. They have anti-inflammatory and anti-carcinogenic properties as well [39].

The glycoside fraction of the mango kernel oil was between 4.16 and 8.35 g/100 g, where the maximum and minimum glycoside contents were represented by Bush kernel oil (8.35 g/100 g) and Kent kernel oil (4.16 g/100 g), respectively. Bush kernel oil has relatively high glycoside content, which may have cardiovascular benefits and be used as a natural sweetener. Research by Nadeem et al. [9] and Das et al. [40] suggested that increased levels of glycosides in mango kernel oils lead to potential heart-healthy qualities, implying that Bush kernel oil has the potential to be useful in dietary formulations targeting heart health. Glycosides have been appreciated for their vast array of biological activities, such as promoting heart health and serving as natural sweeteners with therapeutic applications [41].

The anthraquinone content of the mango kernel oil was highest in Peter kernel oil (3.15 g/100 g) and lowest in Bush kernel oil (1.16 g/100 g), indicating more potent laxative and antimicrobial properties in Peter kernel oil than Bush. Yadav et al. [42] pointed out that the presence of anthraquinones in mango kernel oils is responsible for their antimicrobial and anticancer activities, thus the speculation that Peter kernel oil would be helpful for therapeutic applications. Anthraquinones are known for their laxative effects, anticancer, and antimicrobial activity [43].

The amounts of triterpenoids found in mango kernel oil ranged from 0.24 to 1.82 g/100 g, with Kent kernel oil having the highest triterpenoid content of 1.82 g/100 g, and Bush kernel oil having the lowest of 0.24 g/100 g, which demonstrates that they have strong potential as anti-inflammatory and antiviral agents. As Masibo and He [44] and Yadav et al. [42] suggested, the higher content of triterpenoids in mango kernel oils enhances its medicinal properties, specifically in

treating viral diseases and inflammatory conditions. Triterpenoids, known for their anti-inflammatory, antiviral, and antimicrobial properties, are also used to boost immune function [45].

The levels of coumarin in mango kernel oil ranged from 0.17 to 1.55 g/100 g, and the Kent kernel oil showed the highest coumarin level (1.55 g/100 g), which can be potentially beneficial as a blood thinner and inflammation-relieving effect. Bush kernel oil had the lowest levels (0.17 g/100 g). Khammuang and Sarnthima [46] and Pinsirodom et al. [47] reported that it is possible that oils with a higher content of coumarin can specifically help in treating cardiovascular diseases and infections, so oils with high amounts of coumarin are expected to be useful as well. Coumarins are aromatic organic compounds exhibiting monitoring of their anticoagulant, anti-inflammatory, and antimicrobial properties [48].

The emodin contents of mango kernel oil varied from 0.71 g/100 g (Bush kernel oil) to 1.29 g/100 g (Kent kernel oil). The high emodin content in Kent kernel oil predicted its possible use for treating constipation and preventing certain cancers. Lebaka et al. [49] and García-Mahecha et al. [50] reported that emodins in mango kernel oils increase their therapeutic characteristics, especially regarding laxative and anticancer properties. Emodins are derivatives of anthraquinone compounds being reported as laxative-inducing compounds, anticancer compounds, and used in traditional practices as antimicrobial agents [51].

The alkaloid contents of the mango kernel oils varied from 5.34 g/100 g to 9.24 g/100 g, with the highest as 9.24 g/100 g in Peter kernel oil and the lowest as 5.34 g/100 g in Bush kernel oil, suggesting a robust pharmacological potential. Aryal et al. [52] showed that mango kernel oils with a higher alkaloid content are more potent in analgesic and anticancer activities, indicating that Peter kernel oil is especially useful in pharmaceutical formulations. Alkaloids are nitrogen-containing compounds with a broad spectrum of pharmacological activities, including analgesics, antimalarials, and anticancer agents [53].

The extracted mango kernel oils' composition of phytochemicals indicates the possibility of their utilisation in numerous healthcare, therapeutic, and cosmetic applications. Dusha (Hindi) kernel oil and Kent kernel oil, high in bioactive compounds, can be promising for their use in medicinal and cosmetic products to reduce inflammation, combat infections, and advance heart health. Bush kernel oil might be a good candidate for nutraceutical formulations due to the presence of flavonoids and glycosides at such levels. With its significant concentrations of alkaloids and anthraquinones, Peter's kernel oil could also be worth investigating for potential use as a pharmaceutical in pain relief and digestive issues.

Physicochemical properties of Mango kernel oil

Table 2 shows the results of the physicochemical properties of oil extracted from 4 different varieties of mango kernels using *n*-hexane. These properties are vital to assessing the oils' quality, stability, and potential uses. The iodine values of the mango kernel oil ranged between 68.50 and 91.37 g/100 g, with Kent kernel oil having the highest iodine value (91.37 g/100 g), hence indicating the highest degree of unsaturation correlating with its high linoleic and linolenic acid content. In contrast, a lower iodine value (68.50 g/100 g) was shown for Peter kernel oil, indicating fewer unsaturations and, consequently, better oxidative stability. Previous studies such as Kittiphoom and Sutasinee [54], Nadeem et al. [9], Yadav et al. [28], and Gurjar and Raj [55] reported iodine values of 60–100 for different varieties of mango kernel oils and different extraction methods. These results align with this range, specifically with high iodine values in oils with high levels of unsaturated fatty acids. The iodine value indicates the degree of unsaturation of the oil or the number of double bonds in the fatty acids. Higher iodine values also indicate greater unsaturation, making the oil more susceptible to oxidation but also more fluid [56].

Results for the peroxide values of the mango kernel oil were from 2.46 to 4.68 mEq/kg oil. The peroxide value of Peter kernel oil was found to be the lowest (2.46 mEq/kg oil), indicating better oxidative stability. In comparison, the peroxide value of Kent kernel oil was found to be the highest (4.68 mEq/kg oil), indicating a higher possibility of oxidation. According to Jahurul et al. [57], Gilbraith et al. [58], and Gurjar and Raj [55], the peroxide values for freshly extracted oils usually range from 2 to 5 mEq/kg. The results of this study corroborate these findings, confirming that these oils are relatively fresh quality but that some are more prone to oxidation. Peroxide value estimates the early oxidation state of oil, which shows how much peroxide is

produced in the oil. Results lower than these peroxide values mean the oil is fresher and has better oxidative stability [59].

The saponification values of the mango kernel oil were between 33.23 and 46.27 mEq KOH/g oil. Kent kernel oil contained the highest saponification value (46.27 mEq KOH/g oil), which means it has a greater proportion of shorter-chain fatty acids. The lowest value was Peter kernel oil (33.23 mEq KOH/g oil), indicating long-chain fatty acids. According to Meziane et al. [60], Yadav et al. [28], and Kouassi et al. [61], saponification values for mango kernel oils range from 30 to 50 mEq KOH/g oil depending on the variety and the fatty acid profile. The values recorded in this research are within this range, highlighting the suitability of Kent kernel oil for soap production. The saponification value is indicative of the average molecular weight of all fatty acids present in the oil (chain length) [62].

The acid value shows the free fatty acid content in the oil, which may be formed by hydrolysis and oxidation. Oil with high acid values indicates degradation, which is unsuitable for edible applications [63]. The acid values of the oils obtained from mango kernel were in the range of 7.75–8.82 mg KOH/g oil. The highest acid value (8.82 mg KOH/g oil) was found in Peter kernel oil, indicating it may be somewhat degraded. On the contrary, Kent kernel oil has the lowest values, indicating better oil quality. As reported by Masibo and He [64], Jin et al. [65], and Sultana and Ashraf [63], low acid values (<10%) are acceptable for most edible oils. The results obtained in this work indicate that all the samples are within the acceptable range, although the Peter kernel oil needs refining to lower the acidity.

The titratable acidity of the mango kernel oil was between 0.84 and 0.93%. Peter kernel oil has the lowest titratable acidity (0.84%), whereas bush kernel oil has the highest titratable acidity (0.93%). These values are relatively low, reflecting that the oils are fresh. High-quality oils tend to have low titratable acidity values to prevent rancidity [28, 66]. Titratable acidity provides information about the oil's

Table 2 Physicochemical properties of oil extracted from 4 varieties of Mango kernels

Parameters	Bush Mango Kernel	Dusha mango kernel	Kent Mango Kernel	Peter Mango Kernel
Iodine value, g/100 g oil	84.54±0.02 ^b	77.35±0.01 ^c	91.37±0.02 ^a	68.50±0.02 ^d
Peroxide value, mEq/kg oil	4.35±0.01 ^b	3.92±0.02 ^c	4.68±0.01 ^a	2.46±0.01 ^d
Saponification value, mEq KOH/g oil	34.02±0.02 ^c	37.44±0.01 ^b	46.27±0.01 ^a	33.23±0.01 ^d
Acid value, mg KOH/g oil	8.27±0.01 ^a	8.39±0.25 ^a	7.75±0.01 ^a	8.82±0.02 ^a
Titratable acidity, (% As Oleic acid)	0.93±0.01 ^b	0.87±0.01 ^b	0.85±0.01 ^b	0.84±0.02 ^b
Specific gravity	0.91±0.00 ^b	0.89±0.01 ^b	0.91±0.01 ^a	0.90±0.01 ^{ab}
pH	4.58±0.00 ^c	4.34±0.01 ^d	5.04±0.01 ^b	5.87±0.01 ^a
Density, g/cm ³	91.00±0.02 ^a	89.00±0.01 ^b	91.00±0.01 ^a	90.00±0.01 ^{ab}
Viscosity, cP @40°C	17.34±4.49 ^{ab}	23.78±0.01 ^a	10.13±0.01 ^b	12.13±0.01 ^b
Smoke Point (°C)	246.33±0.34 ^a	251.22±0.56 ^b	250.00±0.74 ^b	220.00±0.44 ^c
Flash Point (°C)	263.00±0.42 ^c	265.01±0.23 ^c	268.10±0.10 ^b	290.00±0.23 ^a
Fire Point (°C)	340.67±0.44 ^c	351.00±0.20 ^b	280.21±0.12 ^d	380.00±0.31 ^a

Values are means±SE (*n*=3). Different superscripts within the same row show significant differences in mean values among the selected mango varieties

freshness and the possibility of it becoming rancid regarding the acid value. Lower values are desirable [67]. Density and specific gravity tell the heaviness of oil to water. These parameters are useful for storage, transport, and application [68]. The samples show similar specific gravity (0.89–0.91) and density (0.85–0.91 g/cm³), which are characteristic of vegetable oils. Hemavathy et al. [69] and Lebaka et al. [49] report specific gravity and density values similar to these for mango kernel oils, confirming that these oils exhibit characteristics of edible and industrial oils.

Analysis of another important parameter is oil pH, which reflects its acidic and basic condition and its stability and safety for human and cosmetic applications. The highest pH (5.87) was recorded for Peter kernel oil, which is slightly alkaline, while the lowest (4.34) was for Dusha (Hindi) kernel oil, which is very slightly acidic. According to Gurjar and Raj [55], the pH values of vegetable oils are generally slightly acidic; pH usually lies in line between 4 and 6 depending on the extraction method and age of the oil. The results of this study were in line with this report, except for Peter's kernel oil, which was more alkaline; this may be related to the condition of processing used.

The mango kernel oil had a viscosity of between 10.13 and 23.78 cP. The highest viscosity (23.78 cP) was found in Dusha (Hindi) kernel oil, probably due to its high saturated fatty acid content, while the lowest viscosity (10.13 cP) was with Kent kernel oil, which was very closely related to the content of unsaturated fatty acid. According to Saiprabha and Goswami-Giri [70], Khammuang and Sarthima [46], and Jin et al. [65], vegetable oils have viscosity values between 10 and 25 cP at 40 °C. This study found similar values, confirming that the viscosity in tropical mango kernel oils is characteristic of this type of oil. Viscosity describes how resistant the oil is to flow and is an important property in applications like frying or use in cosmetics. High viscosity means that the oil is thicker [71].

The investigation of the thermal properties of mango kernel seed oil from four different mango varieties indicated variations between processes that could have been attributed to variations in chemical composition, particularly fatty acid, impurities, and extraction methods. The smoke point, the temperature where the oil starts to give off smoke and break down, forming volatile compounds, varied significantly between the samples. Bush kernel oil (246.33 °C) and Dusha (Hindi) kernel oil (251.22 °C) exhibited higher smoke points, making them appropriate for application in high-temperature cooking or industrial processes. Likewise, Kent kernel oil, with a higher smoke point (250.00 °C), demonstrates greater thermal stability than Peter kernel oil (220.00 °C). The lower smoke point of the Peter oil may indicate a quicker thermal breakdown, potentially due to a higher level of free fatty acids, oxidation products, or

impurities rather than unsaturation alone. Alphonso mango kernel oil has been found by Gurjar and Raj [55] to variably have a smoke point of between 240 °C and 254 °C. Bush kernel oil, Dusha (Hindi) kernel oil, and Kent kernel oil are also part of this spectrum, indicating that they are more stable at high temperatures.

Although Peter kernel oil has the lowest iodine value (68.50), indicating a lower degree of unsaturation, it exhibited the lowest smoke point (220 °C). This suggests that factors other than unsaturation, such as elevated levels of free fatty acids, oxidation products, or residual impurities, may be responsible for its reduced thermal stability compared to Kent kernel oil (250 °C). The flash point is the temperature when the oil's vapours can briefly catch fire in the air. Bush kernel oil, Dusha (Hindi) kernel oil, and Kent kernel oil flash points range from 263.00 °C to 268.10 °C, suggesting similar resistance for each to the moment of ignition. In contrast, the flash point of Peter Kernel oil (290.00 °C) is significantly higher, which means it ignites at a higher temperature, possibly due to a higher presence of long-chain fatty acids. The fire point is the temperature at which the oil will support combustion for at least 5 s. The fire point of bush kernel oil, Dusha (Hindi) kernel oil, and Peter kernel oil (340.67–380.00 °C) indicates they will not readily catch fire. Kent kernel oil has a lower fire point (280.21 °C), meaning it is easier to ignite, as it may contain higher amounts of volatile compounds.

The thermal properties of various mango kernel seed oils provide a spectrum of information towards their potential applications in food and industrial applications. Bush kernel oil, Dusha (Hindi) kernel oil, and Kent kernel oils are high in smoke, flash, and fire points and can be used for frying and other high-temperature industrial processes. Also, their elevated fire points reflect the appropriate potentiality against fire hazards [72]. On the other hand, Peter kernel oil has very low smoke points but high flash and fire points. While the low smoke point indicates its unsuitability for most cooking applications [73], the high fire point suggests a strong resistance to ignition [74]. This difference indicates the presence of impurities or unusual chemical components that affect the thermal characterization of the oil.

Fatty acid profiles of extracted Mango kernel oils

The profile of fatty acids of the four different mango kernel oils (Bush kernel, Dusha (Hindi) kernel, Kent kernel, and Peter kernel) is presented in Table 3. There are two main types of fatty acids (FAs) in oils: saturated fatty acids (SFAs) and unsaturated fatty acids (UFAs). SFAs do not have any double bonds, so they are usually more stable but not as good for heart health. UFAs, on the other hand, have one or more double bonds and are monounsaturated (MUFAs) and

Table 3 The fatty acid profiles of oils extracted from four distinct Mango kernels

Samples	Bush Mango Kernel	Dusha Mango Kernel	Kent Mango Kernel	Peter Mango Kernel
C10:0 (Capric)	1.21±0.01 ^b	1.59±0.01 ^a	0.21±0.01 ^d	0.54±0.02 ^c
C12:0 (Lauric)	2.23±0.01 ^b	2.05±0.01 ^c	1.23±0.01 ^d	2.63±0.01 ^a
C14:0 (Myristic)	1.47±0.01 ^b	1.88±0.01 ^a	0.47±0.01 ^d	0.54±0.02 ^c
C16:0 (Palmitic)	5.35±0.00 ^a	3.52±0.01 ^b	0.35±0.00 ^d	0.69±0.02 ^c
C18:0 (Stearic)	1.31±0.01 ^b	1.54±0.02 ^a	0.31±0.01 ^d	0.97±0.02 ^c
C18:1 (Oleic)	59.21±0.01 ^b	64.08±0.01 ^a	7.21±0.01 ^d	8.49±0.02 ^c
C18:2 (Linoleic)	12.87±0.00 ^b	20.78±0.01 ^b	47.87±0.01 ^a	50.32±0.01 ^a
C18:3 (Linolenic)	1.36±0.01 ^d	1.82±0.01 ^c	33.66±0.01 ^a	22.72±0.01 ^b
C20:0 (Arachidic)	0.91±0.01 ^c	0.86±0.01 ^d	7.51±0.01 ^b	9.61±0.00 ^a
% Unsaturation	85.47±0.13 ^b	88.34±0.23 ^a	89.80±0.11 ^a	84.48±0.14 ^b
% Saturation	14.53±0.08 ^b	11.66±0.10 ^c	10.20±0.34 ^d	15.52±0.22 ^a

Values are means±SE ($n=3$). Different super scripts within the same row show significant differences in mean values among the selected mango varieties

polyunsaturated fatty acids (PUFAs). These double bonds make the nutritional value higher but the oxidative stability lower [75]. There were more UFAs than SFAs in the mango kernel oil samples tested. This means that the oils are mostly unsaturated and could be used in both dietary and industrial settings where fluidity and reactivity are important. The saturated fatty acids, including capric acid, lauric acid, myristic acid, palmitic acid, stearic acid, and arachidic acid, and unsaturated fatty acids, such as oleic acid, linoleic acid, and linolenic acid, were identified. The relative concentration of each fatty acid is displayed with its standard error.

Kent (89.80%) and Dusha (88.34%) oils had the most unsaturation, while Peter (84.48%) and Bush (85.47%) oils had the least. On the other hand, Peter oil had the most SFA (15.52%), which could explain why it has a lower smoke point in other tests. In addition to the nutritional benefits of unsaturated fatty acid-rich oils, vegetable oil high in unsaturated fatty acids has been beneficial in biodiesel production [76]. With their high unsaturation percentages, oils obtained from Kent and Dusha mango kernels could be suitable for biodiesel production. Moreover, oils containing higher unsaturation percentages are also considered to have a higher flavour and better resistance to rancidity,

making them more suitable for culinary use [77]. Palmitic acid is the most common saturated fatty acid in seed oils (5.35% in bush kernel oil and 0.35% in Kent kernel oil). It is also essential for the oil's solidifying point. The amount of stearic acid in the samples that were tested was different. The highest was Dusha (Hindi) kernel oil (1.54%), and the lowest was Kent kernel oil (0.31%). People use this fatty acid more to keep the oil stable and make it last longer. The results from samples, especially the quantity of palmitic acid in extracted oil (bush kernel oil), were high (5.35%) and consistent with Jin et al. [65], who found palmitic acid content of 4–8% in different mango kernel oils. These fatty acids are responsible for the solidification point and oxidative stability of the oils, which are significant shelf indices life and industrial application [63].

The lowest percentage of oleic acid (7.21%) was obtained in Kent kernel oil and the highest (64.08%) in Dusha (Hindi) kernel oil. High oleic acid content is highly desirable in oils intended for consumption due to its significant stability and health benefits; therefore, Dusha (Hindi) kernel oil is considered the most valuable. The Dusha (Hindi) kernel oil has an important percentage of oleic acid (64.08%), which is significantly beneficial in reducing cholesterol levels and maintaining cardiovascular health. This fatty acid profile is similar to high-oleic sunflower and olive oils, which are improved for their stability and health benefits. Similarly, Kittiphoom and Sutasinee [54] have also reported elevated percentages of oleic acid from some mango kernel oils, raising the possibility of considering some as healthier alternatives to regular oils. Peter kernel oil has the highest linoleic acid content, which is 50.32%, whereas it is 47.87% for Kent kernel oil. Linoleic acid is an essential fatty acid for human health, and the fact that Peter kernel oil and Kent kernel oil show high levels of this fatty acid suggests their potential worth for use as food. Fahimdanesh and Bahram [78] also highlight the significance of linoleic acid for humans, emphasising its role in skin benefits and the immune system. The high levels of linoleic acid seen in these samples demonstrate their potential as important nutritional oils.

Kent kernel oil (33.66%) contains the highest percentage of linolenic acid, while Bush kernel oil has the lowest (1.36%) value. Linolenic acid is a polyunsaturated fatty acid. Higher linolenic acid levels are associated with cardiovascular protective effects but higher susceptibility to oxidation, thus reducing stability and shelf-life levels [79]. Kent kernel oil contains unusually high linolenic acid content (33.66%). Although this fatty acid is good for heart health, it also increases the susceptibility to rancidity, so this oil must be handled carefully, perhaps with the addition of antioxidants to help preserve its shelf life. Meziame et al. [60] reported that oils rich in linolenic acid have been used

in a manner either in cold applications or with antioxidants to avoid oxidation.

The analysis of fatty acid profiles of various mango kernel oils (Bush kernel oil, Dusha (Hindi) kernel oil, Kent kernel oil, and Peter kernel oil samples) demonstrates a considerable variation in fatty acid composition, especially saturated fatty acids to unsaturated fatty acids. This degree of variation also means that these oils could be suitable for many different applications based on the fat content. By comparing our results to recently published data, we describe possible applications of these oils in health benefits. The differences in the profiles suggest that some oils may be ideal for food purposes. In contrast, others may be more appropriate for industrial or therapeutic uses, particularly considering factors like oxidative stability and nutritional value.

Bush kernel oil exhibits a balanced fatty acid profile characterised by moderate saturated and unsaturated fatty acid concentrations. This balance suggests its potential for applications in many areas, from culinary to industrial use. Dusha (Hindi) kernel oil is unique for its high oleic acid, similar to olive oil, and is thus suitable for heart-friendly diets and culinary purposes. Monounsaturated fats are hailed for their stability and health benefits in these contexts. On the other hand, the high linoleic acid content of Peter kernel oil is well recognised for meeting the requirement for essential fatty acids. Additionally, with a reasonably high content of arachidic acid, it appears well-suited for niche or specialised applications, perhaps towards cosmetic or pharmaceutical sectors that require such fatty acid profiles.

In contrast, the high linolenic acid content of Kent kernel oil suggests its applicability in health food or cosmetic products. In such applications, oxidative stability is of less concern than the beneficial effects of linolenic acid, especially the effects on cardiovascular and skin health. The different fatty acid compositions of Kent kernel oil and Peter kernel oil have potential applications for various industries that need specific nutritional or functional properties. Due to their composition and effect variances, these oils could fill different market segments. Reports have been published in this domain that states that Kent kernel oil and Peter Kernel oil hold the potential to be able to be translated into commercial terms due to the appropriate nutritional or functional properties of the products. These oils also have a unique fatty acid profile that could focus on distinctly different market segments in supplement or cosmetic form.

Conclusion

This study proved the potential of mango seed kernel oil as a valuable alternative to conventional fossil-based oils, with applications in various industries such as cosmetics,

food, pharmaceuticals, and energy. The study successfully extracted oil from four different mango types using Soxhlet extraction with *n*-hexane, demonstrating substantial differences in oil output, phytochemical composition, physicochemical qualities, and fatty acid profiles. Bush kernel oil and Kent kernel oil had the maximum output, showing that these types are well-suited for oil production. The phytochemical examination revealed the existence of bioactive components that contribute to the oil's antioxidant and antibacterial characteristics, making mango kernel oil an attractive choice for health-promoting and therapeutic uses.

With its high iodine value, the Kent kernel oil may be more suited to applications needing high unsaturation levels. In contrast, with its lower iodine value, Peter kernel oil provides superior oxidative stability and a longer shelf life. The fatty acid profiles further demonstrated mango kernel oil's adaptability, with Dusha (Hindi) kernel oil's high oleic acid level making it very helpful for heart health and Peter kernel oil's high linoleic acid concentration showing nutritional value. This study highlights that the selection of the mango variety and optimisation of the extraction process is crucial to increasing the production of quality oil from mango kernels, which may contribute to the sustainable utilisation of mango seed waste in the long run. These results serve as a starting point for further research and development in alternative oil production and the potential to enhance the commercial application of mango kernel oil and reduce environmental waste.

Acknowledgements The authors express gratitude for the postdoctoral fellowship awarded to Dr J.B. Hussein by the College of Agriculture, Engineering, and Sciences at the University of KwaZulu-Natal, South Africa, and Modibbo Adama University Yola, Adamawa State, Nigeria, for his release.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by D.S., J.B., S.D., and T.S. The first draft of the manuscript was written by D.S. and J.B., and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Open access funding provided by University of KwaZulu-Natal.

Data availability All data associated with this study are reported in the manuscript and no other data are deposited in any public or closed database.

Declarations

Conflict of interest The authors declare that there is no conflict of interest involved in this work.

Ethical approval The collection of plant material complied with relevant institutional, national, and international guidelines and legislation. Prior to collection, all necessary permissions and licenses were

obtained from relevant authorities in compliance with national biodiversity laws and institutional guidelines.

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